MANAGING THE GAPS IN A REGIMEN OF CONTROL – OPERATIONAL DECISION MAKING AT A NUCLEAR POWER PLANT

Thesis/Project work submitted in partial fulfillment of the requirements for the MSc in Human Factors and System Safety

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Date of submission: 2014-02-18

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Abstract

Nuclear power has significantly improved performance over the last thirty years. This improvement has been based on a philosophy of control. That is, for each issue that must be managed to achieve safe performance, a pre-determined barrier must be established. In addition to the barriers that were designed into the plant, a large range of programs, processes and procedures have been developed to direct the activities of anyone associated with the plant. The premise is that the following of pre-determined procedures in a diligent way will support ongoing plant safety.

But what if an issue arises for which there is no procedure? For serious situations emergency procedures exist to guide operations personnel to place the plant in a safe state. However, the majority of emerging issues are much more mundane and form part of the daily life in the plant. Where an issue is of concern, and it is developing slowly, the nuclear power industry has been encouraging the use of an 'Operational Decision Making' (ODM) process. This process is used to respond rigorously to the issue, generate an appropriate procedure, and help assure ongoing safe operation of the plant.

The purpose of this research was to look in detail at the ODM process as practiced at a large Canadian nuclear power utility. Semi-structured interviews of operations and engineering managers were used to build a consolidated picture of their lived experience as they use the ODM process to address unique situations. Rather than focus on the technical aspects of situations where ODM process is used, the interviews used the 'technical' story as a framework to discus the way the key players think through, and interact with each other, as they work through issues in a team environment. The resulting data provided a rich description of the ODM process as enacted by the participants.

Research of the ODM process is of interest because it illustrates where a traditional problem solving and decision making process is enhanced by social interaction of the participants. The process as lived reaches beyond the traditional control philosophy of nuclear power to provide enhanced input to the decision process. However, the prevalent philosophy of control also appears to inhibit the full value that could be realised from the ODM process, particularly where the current focus is to fill gaps in the regimen of control rather than using the process to obtain a more complete understanding of the system as a whole. Instead of seeing an emerging issue as a challenge to the paradigm of control, the ODM process uses current information about the state of the system, along with a multi-disciplinary approach, to provide thoroughly prepared guidance to the system operators. This approach is already being used to respond to the on-going variations that are now acknowledged as part of managing a complex system. It appears that the social properties of the ODM process add features that help to cope with complexity in the socio-technical systems that now comprise nuclear power utilities.

Acknowledgements

I would like to take this opportunity to thank the organization that agreed to my completing this research on their site. They allowed me free access to their employees, procedures and documentation associated with the topic of my research. I particularly appreciated the support of my colleagues who agreed to participate in the research as interviewees. I know how demanding the life of a nuclear professional is, and I know that you made a real effort to help with my research. Thank you.

Thank you also to my supervisor, Roel van Winsen, who provided tremendous support and encouragement as he guided me through the research process. I thank you for helping me achieve something better than I ever thought possible.

Lastly, I wish to thank my dear wife Carol for her patience and love as I spent many hours making sense of my data and rewriting my words. Your support for me has been incredible!

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LIST OF ABBREVIATIONS

ANO	Authorised Nuclear Operator
CRSS	Control Room Shift Supervisor
INPO	Institute of Nuclear Power Operations
LOCA	Loss of Coolant Accident
ODM	Operational Decision Making
OM	Operations Manager
SM	Shift Manager
SOE	Safe Operating Envelope
TMI	Three Mile Island
WANO	World Association of Nuclear Operators

EN1,2,3	Code for Engineering Manager interviewees
NS,1,2,3,4	Code for Nuclear Safety Advisor interviewees
OM1,2	Code for Operations Manager interviewees
SM1,2,3,4	Code for Shift Manager interviewees

INTRODUCTION – HISTORY AND THEORY

The development of a 'philosophy of control' in nuclear power

Over the last 35 years events within the nuclear power industry have had a significant impact on the development of the industry. Three-mile Island (1979), Chernobyl (1986) and Fukishima (2011) are well known publically through broad media coverage. Less well known is the event at the Davis-Besse plant in Ohio (2002) where serious corrosion resulted in weakening of the reactor vessel, narrowly avoiding a loss of coolant accident (LOCA). These events all shaped the development of the organisations and leadership that are responsible for safe operation of the plants today.

The initial focus of improvement after Three-mile Island (TMI) was 'technical' in nature in its emphasis on better equipment reliability and in improvements to training and procedures. In addition it was recognised that the industry had failed to learn from its own experience, and had managed to standards which consisted of merely satisfying regulatory requirements. The industry response to TMI in the USA was significant and resulted in the forming of a unique utility association. This organisation, the Institute of Nuclear Power Operations (INPO), was the focal point of the development of a nuclear 'community' which exercised a great deal of peer pressure over all of its members. Through this process INPO was able to lead improvements across the US nuclear industry by the use of a peer evaluation process, the accreditation of training programs, the analysis and sharing of operating experience, and providing focussed support to deal with specific problems at individual plants. INPO managed to establish new normative standards that expected ongoing pursuit of excellence rather than the mere meeting of government regulation (Rees, 1994).

When INPO was first established it faced the issue that the fledgling nuclear power industry had no experience base from which to identify and draw upon best practices. It turned to the US nuclear navy where the famous Admiral Hyman Rickover had established a nuclear power submarine service that had an excellent safety record. Rickover had an almost prophetic view of the dangers associated with nuclear energy, and the need to respect both the engineering design features and the need for 'painstaking care' in nuclear operations. Thus INPO hired many ex-navy personnel and used navy practices to provide a starting point for the rapid improvement of civilian nuclear power operations. As INPO and the industry matured and gained further civilian based experience, the standards to which INPO holds the industry accountable have become based on best practice in industry. However the core principles (adopted from US navy practice) of clear command structure, and discipline in the application of procedures, still provides a strong core philosophy within the industry(Perin, 2005; Rees, 1994).

Then there was the Chernobyl accident. This event raised the first warning flags about the influences of culture on safe plant operation. The term 'Safety Culture' was coined by the International Atomic Energy Authority (IAEA) in its follow up review of the events leading up to Chernobyl (IAEA, 1991). The prevailing attitudes and beliefs throughout the organisation which operated Chernobyl had created an environment where "the operators … seemed to have lost all sense of danger" (Legasov, as quoted in Mosey, 1990, p. 92). The nuclear industry responded with additional programs and procedures to reduce human error, to create a safety conscious work environment, and to improve the safety culture at each plant (Rogers, 2013).

The organisations that manage nuclear power today have grown into complex socio-technical endeavours. Nuclear utilities continue to be operated in a very highly structured way with great emphasis on organisation structure, programs, processes and procedures. Each program contains design and risk information, along with the desired methodology to control the risk. New issues and lessons learned from experience are managed by the revision of, or by the creation of, more rules and procedures. The identified requirements for safety are thus embedded in the plant programs and procedures. Plant managers and workers are expected to assure ongoing safety by adhering rigorously to the procedures (Rees, 1994; Rogers, 2013). Perin further illustrates the industry's thinking behind this culture of control:

> In this high hazard world, technologists' explicit claims pivot around the dynamics of control theory, meshed with productivity concepts such as optimization and efficiency, to produce protective bywords such as command and control, defense in depth, feedback, margins of safety, procedures, rules, system reliability, training (2005, p.xii).

Ultra-safe, but is that enough?

This philosophy of control for achieving safety in the nuclear power industry has been successful to the extent that the industry can be included in the category of ultra-safe system.

> Ultra-safe systems, where risk of disaster is below one accident per 100,000 or even one million safety units. Regularly scheduled civilian flights, railroads (in Europe) and the nuclear industry are examples of industries having reached this level (Amalberti, 2001, p. 111).

In spite of the ultra-safety level of industry performance significant incidents have occurred, as illustrated by some recent examples. The event at Fukishima in Japan in March of 2011 is an example of a major accident. Smaller events also challenge safe operation. "The nuclear power industry world-wide was surprised by the effects of the surge on the emergency power system…" during a serious operational event at the Forsmark nuclear power plant in 2006 (Sanne, 2012, p. 240). Another recent example occurred on March 31 in 2013 when a 500 tonne component was dropped during maintenance work at the shutdown 'unit 1' of the Arkansas Nuclear One plant. One person was killed and eight others were injured. Additionally, the electrical system in the adjacent 'unit 2' reactor of the plant was disturbed, resulting in an automatic shutdown from full power. An emergency state existed for 10 hours as operators stabilised the plant electrical system. (World Nuclear News, 2013)

In order to make improvements beyond the existing performance of ultra-safe systems Amalberti suggests different approaches are required. This is in addition to the existing historical reliance on elimination of human error, improving equipment reliability, and the detailed specification of operator action in procedures. The need for additional diverse approaches to safety is necessary due to the nature of accidents being different at the ultra-safe level. For example, incidents usually do not result from serious breakdown or error, but are more likely to arise due to a combination of circumstances that are difficult to detect using the historical approach (2001).

Traditional safety approaches rely on a linear approach that establishes a cause for every effect, and designs a barrier by way of physical plant, automation, or procedure, to avoid the appearance of the unwanted effect. Unfortunately, as the system becomes more complicated it becomes more difficult to predict all the unwanted interactions. Ultimately the system will develop to the point where, "… complicated systems become complex because they are opened up to influences that lie way beyond engineering specifications and reliability predictions" (Dekker, Cilliers, & Hofmeyr, 2011 p.942). The behaviour of a complex system cannot be broken into its constituent parts because the complex system has properties that emerge from interactions and relationships between the system components. Such systems are non-linear and adapt themselves based on their history. Such systems, by definition, cannot be fully described by reductive analysis. In reality, " … barriers, as well as professional specialization, policies, procedures, protocols, redundant mechanisms and structures, all add to a system's complexity" (Dekker et al., 2011 p. 942) .

Complexity and control in nuclear power

Even though the word complex has long been associated with nuclear power the consequences of working in a complex system have not yet been fully recognised. The philosophy of control does not appear to have evolved to take account of the growing complexity of the nuclear power organisations. Referring to a case study of the Forsmark incident,

> [this] case suggests that organizational learning from nuclear power incidents do not match the complexity of the risks the industry faces and more than likely reproduces latent errors… Experts are aware of these problems but they lack the conceptual and regulatory means to address them. The contemporary regulatory regime relies on mechanistic models for understanding organizational processes where instructions and procedures predominate as tools for understanding and controlling processes, complemented with an attitudinal or moralistic understanding of safety culture and trust in the robustness of the physical plant to withstand errors. (Sanne, 2012, pp. 248-249).

Perin uses the term 'calculated-logics' to describe the existing philosophy of control in nuclear power (2005). The notion of calculated-logics represents the engineering approach to manage risk, the assumptions that are embedded in the plant design basis, and the rules and procedures that have been developed to manage the risks and operate according to the design assumptions. This same notion is carried through into the typical industry response to incidents where, for example, an issue will be prevented from re-occurring provided that revised procedures are followed rigorously (Perin, 2005).

This philosophy of control is based on traditional Newtonian science. The assumption made is that the system as a whole can be understood and controlled by analysis of the system parts. Then the system will be safe as long as the parts function as intended, and that they are operated with the pre-defined procedures that contain operation within the design assumptions. If the system fails then something must have broken, and the broken part must be identified and corrected. In the socio-technical systems that comprises the utility organisation and its safety critical work, the human interactions are considered in the same way. Human behaviour is treated mechanistically, and frequently a human action that results in an unwanted effect is labelled as human error (Dekker et al., 2011).

This traditional reductionist modelling of systems is incomplete in that it does not fully describe the tasks, or the decision-making processes, involved in managing a complex system on a daily basis. The structured task analysis used for training, and for the development of procedures, cannot take into account the full range of possibilities of local circumstances, interactions with other activities, and the environmental context. Ongoing decision-making does not consist of a string of discrete decision events backed up by a full analysis of alternatives. Rather, "operational decisions … [are based] only on the information which, in running context, is necessary to distinguish among the perceived alternatives for action"(Rasmussen, 1997 p. 188). Rasmussen continues:

> Human behaviour in any work system is shaped by objectives and constraints which must be respected by the actors for work performance to be successful. Aiming at such productive targets, however, many degrees of freedom are left open which will have to be closed by the individual actor by an adaptive search guided by process criteria such as work load, cost effectiveness, risk of failure, joy of exploration, etc. The work space within which the human actors can navigate freely during this search is bounded by administrative, functional, and safety related constraints. The normal changes found in local work conditions lead to frequent modifications of strategies and activity will show great variability. (1997, p. 189)

The front line reality!

There is limited empirical research addressing the routine decision making by operations managers, particularly where such activity is regarded as successful. Research on decision making in safety critical industry has tended to focus on the management of crisis under significant time pressure, or the retrospective analysis of significant events. However, the studies by Perin (2005) and Hayes (2012) do look at the day-to-day trade-offs made by operations managers under more routine conditions. Their empirical research in nuclear power plants confirms the existence of gaps and variations that require ongoing assessment and adjustment, as suggested more generally by Rasmussen (1997). Obvious risks, particularly high-risk situations, can be managed by pre-determined procedures. The problem is not so easy when the work of operations managers is about managing the low and medium risk of variations in plant performance. This is further complicated by the need to manage other variations in the socio-technical system such as staffing, scheduling conflicts, or the availability of replacement spare parts. The impact of any malfunction, incident, slip-up or ambiguity must be considered in relation to the ongoing safe operation of the nuclear plant. (Hayes, 2012; Perin, 2005).

The coping mechanism displayed by operations managers, as they oversee the operation of the plant on a daily basis, can be labelled as 'real-time logics':

> [R]eal-time logics reduce and handle risks that design calculations have not anticipated. The real-time logics of station experts accompany them as they try to hew to procedures and rules. They draw on judgement and inference when interpreting conditions in the moment. (Perin, 2005, p. 198)

In contrast to the highly structured and documented form of the calculated logics, real-time logics respond to the day-to-day issues through "observation, discussion, experience, judgement, insight, and interpretation" (Perin, 2005, p. 203). Where the calculated logics are weak or provide no direction, real-time logics fill the gaps of calculated logics to maintain control. As such, operations managers provide an important contribution to the safety of the system by,

> … shoulder[ing] risks no one has foreseen … between designers intentions and how they are being realized. Even with wide safety margins and detailed operating procedures, missteps, missing resources, miscommunications or mistakes have to be found a put right before they can turn into a tragic flaw. … Most of the time those responsible for handing risks … defuse

> worrisome situations, prevent surprises and keep any that appear from becoming more serious. (Perin, 2005, p. ix)

Hayes (2012) study showed that, when faced with a 'new' emerging issue, operations managers work to maintain the barriers that have been established previously by engineering design or through formal organisation rules and procedures. If a barrier is judged to be weak or compromised the operations manager will establish a self-imposed temporary limit, or a 'line-in-the-sand', to compensate.

> This [line-in-the-sand] is similar to a limit imposed by a formal operating instruction, but it is specific to the particular situation at hand and is developed at the time by the crew based on the available information about the state of the system. Within this self-imposed limit, personnel continue to monitor the situation and attempt to solve the problem. If the situation is not resolved before the limit is reached, then the plant is shut down. (Hayes, 2012, p. 426)

Operations managers have no choice but to work with their system as a whole since they are responsible for operation of the system and for meeting the safety and production goals of the organisation. The operations managers, as individual agents, do appear to be providing adaptability as they work to cope with the various pressures, as they work to understand the status of their processes, and act to maintain safety and productivity. This individual adaptability does contribute to the success of the organisation on an ongoing basis. However in practice real-time logics "are likely to be documented and analyzed more in terms of their failures than their successes" (Perin, 2005 p. 223). Retroactive reviews of actions taken by managers prior to an event frequently reveal an issue with the real-time logics being applied. This frequently results in the application of the 'human error' label to the manager's actions, even though the full consequences of the actions can only been seen with the benefit of hindsight.

An 'operational decision making' process in nuclear power

The nuclear industry has developed an 'operational decision making' (ODM) process to give guidance to operations managers in handling emerging issues for which there is no procedure. In dealing with the complexity of nuclear operations the industry recognised the need to address this gap based on its own analysis of industry events. Nuclear utilities have incorporated this guidance in their own procedures (Bruce Power, 2011). Given that the ODM process is used for issues that are not perceived as an immediate threat to safe operation, time is available for operations managers to assemble a team with the expertise necessary to address the problem. Team members are expected to bring their specialised knowledge and experience to the table. The team is responsible for making recommendations as to the best course of action by considering the specifics of the emerging condition in aggregate with the known plant status and the expected operating environment. Recognising that the ODM process is activated to deal with conditions that have not been foreseen, the staff are frequently challenged by the novelty of the situation. This then requires ODM team members to exercise judgement based on their individual skill and experience, as to what forms an acceptable path forward, and what is considered safe.

The current ODM guidance in North America does appear to introduce some of the characteristics considered helpful in the management of complex systems. For example, the formation of a team with diverse knowledge, and empowering each team member with the authority to state their concerns, can result in a "diversity of narratives (that) can be seen as an enormous source of resilience in complex systems … not as a weakness" (Dekker, 2011 p. 201). Dekker goes on to stress the need to gather as much information as possible, and consider as many consequences as possible, when making key decisions in a complex system. Even though Dekker states that it is impossible to definitively 'manage' a complex system, and that any plan will inevitably be incomplete, a diverse approach will help improve the chances of success.

Relevance and Aim of Research

The day-to-day decision-making by operations managers is an important part of the construction of safety in managing a complex socio-technical system such as a nuclear power plant. Rather than leave operations managers without procedural guidance for unforeseen situations, the nuclear industry has implemented the ODM process. This process is intended to assist operations managers in their assessment and addressing of emerging issues during their daily work.

The very recognition that situations may emerge that are not addressed by procedural instructions is an important first step beyond the overarching control based philosophy. The industry ODM process does appear to support the management of a range of issues that have not been identified and addressed by pre-determined barriers and controls. In effect the ODM process is attempting to provide (procedural) support to the more significant issues being addressed by 'real-time' logics. However, the prevailing philosophy of control in the nuclear industry, along with its associated assumptions, is very strong and it can limit the full appreciation of issues that arise due to system complexity.

Perin (2005) identified issues by which the philosophy of control influences the worldview of the operations managers within the system. As an example, operations managers still rely heavily on the designed barriers, whether they are engineered or procedural. This makes it difficult for the managers to recognise where weakness in individual barriers may combine to cause an issue. As an example, in 2002 significant damage was discovered at the Davis-Besse plant in Ohio. The damage resulted from an incipient crack in the reactor vessel head that allowed corrosive coolant to eat away a football-sized chunk of the reactor pressure vessel. The Davis-Besse organisation had previously implemented management control programs to monitor reactor vessel leakage, and to monitor the condition of the reactor vessel. Each program focussed on known risks of reactor coolant coming into contact with the reactor vessel material, and the danger of damaging the reactor vessel through corrosion. In this event, weakness in each of the independent programs combined to allow the corrosion to continue over an extended period of time. Such complex interaction amongst the barriers is difficult to predict within a control-based regimen.

The philosophy of control also leads to a hierarchy in the relative value the industry places on different kinds of knowledge. "The higher value assigned to calculated logics assumes that quantitative knowledge is more useful for reducing uncertainty"(Perin, 2005, p. 201). Preference is given to quantitative versus qualitative information, or measurable over un-measureable. For example, an engineering assessment will be given higher status than the report from a field maintainer in the plant. However, when faced with unique emerging situations consideration must be given to a much broader range of information. "[As] real-time logics get into gear ... local experts draw on memories, observation, experience, judgement ... [and] on best-practices and lessons learned from event reports, and on professional experience" (p. 201). The collection and consideration of diverse data in the ODM process is also critical, and the institutional hierarchy of knowledge may also affect this.

There does not appear to be any detailed research that describes the current ODM process. Hayes (2012) mentions that ODM procedural guidance had not yet been implemented at the time of fieldwork at a UK nuclear plant. As such it would be of value to look at current ODM process in some detail in an operational environment, especially given that it has been established for almost ten years in North America. Such a study can obtain a deeper understanding of how the current approach to ODM is supporting operations managers to overcome the limitations of the calculated logics of control. The study can highlight the practices that have been established and identify the social framework, relationships and assumptions upon which the process depends.

The objective of the research is to identify to what extent the control philosophy in nuclear power is influencing the thinking of its key agents when faced with complex emerging 'unique' issues. The literature shows that agents may be heavily influenced to maintain the control approach prevalent in the industry. As such, the 'operational decision making' process may be hampered from recognising more diverse ranges of issues and actions, which may help in dealing with complex situations. It is hoped that this research can form the foundation for future work on how to supplement the control-based philosophy in the nuclear power industry. This gives rise to the research question that is the basis of this thesis:

"To what extent is the 'operational decision making' process of nuclear power operations managers part of the nuclear industry's philosophy of control?"

METHODOLOGICAL APPROACH

In order to study the ODM process it was important to use an approach that can consider the ODM process as an integrated social process. The activities initiated once an ODM begins include a great deal of discussion in organised meetings. These discussions provide opportunities for the various participants to share various forms of information, share ideas and concerns, and form opinions based on their own perspectives. Some information is derived from engineering analysis. Other information is derived from the experience and knowledge of the various experts involved. The final output of the ODM process depends on how the information gathered is processed by the various experts involved in the ODM team.

The approach to this research had to consider both the view of each participant and the interactions with other participants in order to provide a complete picture of the ODM process. In addition, the research sought out the underlying beliefs and assumptions each participant draws upon to develop their thoughts and opinions. An ethnographic approach was therefore used to, "produce … in-depth understanding of real-world social processes. Properly done, it provides detailed insight into the concepts and premises the underlie what people do – but that they are often unaware of" (Forsythe, 1999, p. 129).

Given that the ODM process is designed to deal with unforeseen situations it would have been very difficult to design a simulation study. The research was therefore focussed on the actual working environment by using actual ODM experience as a basis for exploration of the ODM process. The

ODM process is used approximately 20-30 times a year at a typical plant, and as such provided a good source of real-life situations to study.

The ethnographic approach was used to develop a ‘thick description’ of the ODM process. In this context ‘thick description’ refers to the collection of detailed information about behaviour of the participants, the thinking of the participants, and the context in which the ODM process unfolds to address a plant issue. To support the ethnographic methodology data was collected using interviews and review of documentation. The following sources were used:

- The ODM process and expectations as described in the utility governance system.
- Interviews with some of the key participants in the ODM process.
- A review of the information recorded about the actual ODM event.

Interviews were used to develop a detailed picture of how participants work their way through an ODM event. A semi-structured interview process was used to collect data from a cross section of key participants in the ODM process (see Appendix A for the interview protocol). The interview was based on actual events chosen by the participants. Even though this study was not intended to use a case study approach to actual event situations, it was useful to use the events as a focal point for the informants to talk about the ODM process at large. In order to make the interviews as effective as possible the interview format was based on a methodology suggested by Crandall et al in their text on Cognitive Task Analysis (CTA)(Crandall, Klein, & Hoffman, 2006). CTA is well suited to study “work settings in which the knowledge and reasoning of individuals play a role, but so do the cognition and reasoning of larger groups of people including, teams and even entire organisations” (Crandall, Klein, & Hoffman, 2006 p. 2). As such, the interview technique developed by Crandall et al (2006 p. 73-83) was used as a basis for the interview format. A key feature of this format is that multiple passes are made through an ‘event’ to build a deeper picture of the ‘story’ behind the event. Once the incident has been described and a time-line developed, then probe questions are used to “elicit the cues and information available in the situation [and] the meaning they held for the participant” (p. 79). In summary, the interview firstly elicited a general description of the event, secondly discussed how the participant approached the event, and thirdly, discussed the social interactions during the ODM meetings, using the event timeline as a basis for each sweep through the event. The interview plan and examples of probe questions is included in Appendix A.

Documentation was reviewed to provide more detail in two aspects. Firstly, the antecedent expectations and guidance given to the participants was reviewed. This focused primarily on a procedure issued to give specific guidance to managers on the ODM process (Bruce Power, 2011). Secondly, the plant record system was reviewed for information that has been written about individual ODM events. This data helped to support the creation of the thick description, as mentioned above, but also provided information about the ‘trail’ that is left to record the ODM event.

To answer the research question, the data collected was reviewed, within the context of the ethnographically derived description, for common features and constructs revealed by participants in the ODM process. The actual experience of the participants gave important information about the social framework, relationships and assumptions upon which the process depends, as well as information about how the process is affected by the guiding paradigm of control.

Data Collection

Prior to initiating data collection and contacting interviewees I met with senior utility staff to explain the purpose of the study, the arrangements for confidentiality and control of information, and the interview format. Data that comprised written material was made available through a designated utility contact person.

The written procedure for ODM was analysed prior to starting interviews. The actual lived experience of the ODM process was obtained through semi-structured interviews of individuals who have had significant involvement in the process. The population of key managers involved in the ODM process include, Operations managers (OM), Shift managers (SM), Engineering managers (EM), and Nuclear-safety advisors (NS). A total of 13 interviews were completed, two OMs, three EMs, four SMs, and 4 NS advisors. The nuclear experience level ranged from 4 years to 31 years with an average of 19 years. A total of 16 different scenarios were discussed where the ODM process had been used to determine the path forward. These scenarios progressed over time frames ranging from a few hours, up to several weeks. All the scenarios met the entry criteria for the ODM process except for one example of a steam leak which got worse as the ODM process was being initiated, resulting in the plant being shutdown immediately for repairs.

Analysis

The interviews and document review provided material to develop a 'thick description' of how nuclear operations managers use the ODM process to address issues for which there is no pre-determined procedure. Each interview captured an interviewee's thoughts and actions as they interacted with the ODM process, and with other participants in the process. Interview data was compared with the governing documentation to understand the influence of governance on the ODM process, but also to identify any differences between the process as imagined, and the process as practiced.

The discourse revealed by the analysis of interviews and documents was examined closely for meaning to reveal the guiding paradigm. For example, the use of the word diversity, or the implementation of a diverse process, can be seen in at least two different ways. Within the philosophy of control the term diversity is defined as a design objective where systems and barriers are built from different concepts, from different designs, with equipment from different manufacturers. Hence diversity is an engineering control defence against common-mode failure. In contrast, diversity in a paradigm of complexity "can be seen as an enormous source of resilience in complex systems, not as a weakness. The more angles, the more there can be to learn" (Dekker, Cilliers, & Hofmeyr, 2011 p. 944). When approaching the interview data from these two possible paradigms, what does diversity mean to the participants and how does that impact the ability of the ODM process to identify issues that relate to interactions and relationships rather than the maintenance of or creation of new barriers.

Ethical Considerations

I obtained agreement with a major nuclear power utility to perform the research at their facility in Canada. This company agreed to provide access to staff and documents relevant to the research project. This agreement was at no cost, no remuneration, or any other sponsorship support other than the time of the selected informants. An agreement was in place between the researcher and the company to cover this arrangement.

Given the highly sensitive public reputation of the industry, and the need for the industry to interface with a large number of regulators, it is important that any published research be sensitive to corporate reputation. Ongoing communication throughout the research project between the designated company contact and myself ensured that any issues that may affect corporate reputation were identified. The research agreement had the proviso that the company review the research thesis prior to evaluation or publication. The company has acknowledged that the thesis will be published upon acceptance by the university.

This study was about people doing their work and what are the social and historical influences. It did not include the gathering of sensitive personal information. It is also not about making judgements about what is right or is wrong. It is also not about comparing the relative performance of individuals, nor about auditing performance against industry or regulatory standards.

In order that each informant be comfortable with involvement in the study an informed consent form was reviewed with the interviewees that covered the purpose of the study, the name and background of the researcher, and the names and contact information of the supervisor and assessor. The form included a summary of how notes and recordings will be kept secure and that this data will be destroyed after a time interval that allows for academic verification of the research. The data will not be made available for any other purpose. Individuals will not be quoted by name, however due to the small sample size of some of the roles it will be difficult to guarantee anonymity. In these cases the researcher will contact the informant for specific permission to use the quotation. A copy of the final research paper will be made available to each informant. Each participant signed the consent form to acknowledge their voluntary participation and their approval to record the interview prior to collection of data. A copy of this form was filed with the research files.

I complied with generic ethical guidelines for performing this type of research (Hermerén, 2011). In addition, to complete a valid and reliable study it was important to acknowledge my own experience as an 'insider' with thirty years of previous nuclear experience. This experience was of considerable advantage in that the technical language, the form of the issues, and the structure of the organisation were very familiar. However, this could also lead to easy acceptance of observations as fact, the inability to see tacit knowledge and assumptions, and to be caught in the belief system. Forsythe (1999) speaks directly to this issue and offers the comfort that " ethnography usually works best when conducted by an outsider with considerable inside experience" (p. 130). Good ethnography in turn then requires maintaining mental distance and systematic methodology. This in turn required me to be clear about my methodology and ensure that all my work was linked to the evidence obtained from the interviewees.

RESULTS AND ANALYSIS

Organisational context

The utility site has two plants of similar design with each plant containing four reactors and the associated turbines and generators. Each plant has a standardised organisation that provides all the primary support to the operating facility. The plant organisations contain the functions required to operate and maintain the plant, which include operations, maintenance, station engineering, chemistry, safety, performance improvement, and scheduling. The utility organisation also includes a central corporate organisation that provides support to the two plants. The central functions include design and specialist engineering, regulatory affairs, emergency management, security, training, human resources, finance, IT, supply chain and corporate affairs. Corporate program managers support and maintain the programs, processes and procedures that govern activity within the corporation.

The organisational hierarchy and the authorities for approving action are clearly defined in the organisation. The programs that govern the activity of each major program are also identical at each plant. For example the overall program to manage operations is the same at both plants, and within the operations program the procedure for operational decision-making applies to both plants. The plant Operations Manager (OM) is the 'Senior Operating Authority' and is accountable for the safe operation of that plant. Any procedure issued to plant operators to manipulate the plant has to be approved by the OM. This includes any short-term instructions that may result from emerging plant issues.

Plant operational activities are managed on a 24-hour basis under the leadership of the duty Shift Manager (SM). The SM leads a crew of operators based in the control room. Each of the four reactor/generator units is under the oversight of an Authorised Nuclear Operator (ANO) who is responsible for manipulation of the controls. The Unit ANOs and the operators in charge of common support systems and the fuelling systems, all report to a Control Room Shift Supervisor (CRSS). The SM, CRSS, and ANOs are all licenced by the regulator for their role in plant operations. The SM always has access to the OM or delegate 'duty manager' via pager and/or phone. The OM maintains a 'duty manager' list to ensure the SM always has access to himself, or a senior manager with the delegated authority of the OM.

The plant operators continually monitor the plant very closely. They have ongoing discussions with the CRSS and SM of any issues that generate concern. The urgency of any issue depends on where the issue fits within the understood system limits as defined in operating documentation. It also depends on the rate of progress of the issue towards any limit and the amount of margin remaining. In conditions of rapid deterioration the duty crew enters a pre-defined 'response to upsets' where all duty operators are summoned to the control room and adopt a pre-defined response. The duty SM will follow a conservative decision making process to stabilize the plant in a known safe state using normal procedures, abnormal incident procedures, or emergency procedures. In the event that an issue has immediate operational significance or has more substantial implications, then the duty SM can contact the OM directly via phone or pager to discuss immediately. A duty manager is always available who has the authority of the operations division manager. The primary sources of issues that enter the ODM process arise from this kind of direct monitoring of the plant.

A nuclear power organisation also has 'system engineering' staff that are tasked with monitoring the overall performance of their assigned systems. Where operators are monitoring the overall plant on a minute-by-minute basis, the system engineers are collecting in-depth data about the longer-term performance and condition of each plant system. If engineering staff recognise a significant issue from their own analysis, observations, or industry experience, they follow an engineering evaluation process by which, ultimately, they inform the duty SM and the Operations Manager. The engineering evaluation process has criteria for the level of verification, multi-discipline review, and level of authority that is required to respond to any identified plant issue (Bruce Power, 2013b). This is the other source of issues that enter the ODM process.

Safety is addressed in both physical plant design, and in the organisational processes that govern operation of the plant. The term 'reactor safety' is used to capture all of the systems and processes that manage the unique hazards posed by a nuclear power reactor. Ultimately the aim of reactor safety is to manage the overall risk to the public from the operation of the facility. The key principles of reactor safety can be summarised simply by the industry maxim 'control, cool, contain'. Reactor safety is assured by 'controlling' the power generated by the reactor core, 'cooling' the reactor core to maintain its temperature within design limits, and, 'contain' the radioactivity that resides in the reactor core. The plant is designed with structural features to implement control, cool and contain as part of the normal operation of the reactor / generator unit. Additional designed safety features are included to address a set of design basis events such as Loss of Coolant Accident or a Loss of Regulation. These safety systems comprise the automatic shutdown systems, emergency coolant injection systems, and the containment system. The design assumptions and analysis form part of the 'safe operating envelope' (SOE) of the plant.

In addition to the physical plant, the implementation of control, cool, contain must also be carried into the governance and procedures by which the plant is staffed, operated and maintained. These non-structural elements guide the power plant staff in how to manage their work, and also provide specific instructions on how to operate the plant safely. It would be overwhelming to have to consider every design constraint each time an operator had to manipulate the plant, so the required operating limits are embedded in the operating procedures. Operator training is then based on these procedures as well as being used in the plant. The collection of procedures known as the 'operating manual' is an important vehicle to ensure all the requirements are met, and as such it is expected that the operating manual is used with strict adherence at all times.

> Operators are expected to use approved procedures when performing operations that directly manipulate plant equipment. The only exception to this requirement is when taking action in response to emergency condition[s] … If a procedure is not available then do not proceed with the operation until a procedure has been approved. (Bruce Power, 2013b. p. 39)

This context section shows that this nuclear power utility is operated in a very highly structured way with great emphasis on organisation structure, programs, processes and procedures. This also shows that the utility is operated using the guiding philosophy of control that is prevalent in the nuclear industry. As such, the use of a large set of explicit pre-defined procedures is a very important part of the safety philosophy. But how do the organisation and its front line managers respond when a situation develops for which a procedure has not been provided?

Operational Decision Making as documented

The ODM process

The ODM procedure is part of the suite of procedures that are used to define requirements and guide the operations staff in the safe operation of the plant. The ODM procedure, along with its associated 'Operational Decision Making Checklist' (Bruce Power, n.d.), is designed to address the issue of situations that arise where the path forward is not addressed by existing procedure.

> This procedure provides a structured approach for making operational decisions to support safe, reliable plant operation. The focus of this procedure is on the response to degraded/degrading equipment or plant conditions that are inside OP&P[1] limits and are not clearly defined by procedures. These are situations typically involving reductions in safety margins that evolve over days or weeks. (Bruce Power, 2011, p. 2)

The procedure also defines carefully when it should not be used. For example, "[i]f time does not allow for advance consultation with resource groups and the duty manager, the operating crew shall place the plant in a safe state and then seek guidance on the follow-up actions required" (Bruce Power, 2011 p. 3).

The stated objective of ODM is to support the making of decisions such that "decisions are based on a full understanding of short and long term risks and the aggregate impact of conditions associated with various options" (p. 4). The procedure defines ODM as, "the processes and attributes employed by personnel in response to abnormal or degrading equipment or plant conditions" (Bruce Power, 2011 p. 2). The format of the procedure includes both the instructions to enact the process, with the attributes intermingled with the descriptions of each process step. The ODM process is initiated when approved by the OM after a discussion with the duty SM. A team with a predefined minimum membership enacts the ODM process. The output of the ODM process is presented to the OM for final acceptance or rejection. Lastly, the procedure also emphasises that "a structured approach must be followed" (p. 4). This emphasises the general expectation that you must be 'in process', or in other words, following the procedure, when faced with the defined entry conditions.

The core of the ODM process has four parts that include: describe the operational issue, evaluate potential decisions, recommend decision, and implementation plan. In essence, the ODM team works through the four parts and uses the checklist to help consider if each part has been satisfactorily completed.

The first part is to describe the operational issue. The purpose of this step is to clearly define the problem, its scope, and ensure that any supporting information is validated. This step is also used to identify the consequences of the issue, particularly the 'worst case scenario'. The checklist has a section to support this step of 'defining the problem', and it lists a series of memory jog style questions such as consideration of safety consequences, consideration of aggregate impact with other plant issues, and whether formal troubleshooting processes have been considered. It also asks several questions around validation of data, "Have all the facts and conclusions been documented and verified. Is there enough data to support the conclusions? Are all of the indications received fully explained?"(Bruce Power, n.d., p. 3)

The second part of the ODM process is 'evaluation of potential decisions'. Again the procedure refers the team to the corresponding checklist section where questions ask, "have all potential

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[1] The Operating Policies and Principles (OP&Ps) are laid out in a high level document which is agreed with the Regulator. The document contains three types of guidance. (1) Authorities to provide control room supervision, to operate the controls and to approve plant procedures (2) Principles to perform maintenance and testing work e.g. a system shall be placed in a safe state prior to maintenance, and the system shall be tested prior to being made available for service (3) A list of key technical parameters, e.g. maximum reactor power, maximum system pressure.

alternatives been considered?" and, "has each potential solution been rigorously evaluated?" (Bruce Power, n.d., p. 3). The checklist includes prompts to consider, in addition to risks and consequences, whether there are issues with license compliance, safety margins, and consideration of un-intended consequences. The checklist also includes prompts to consider other risk or problem evaluation tools.

The third part of the ODM process is the 'recommended decision'. To come to a decision the checklist advises the group to "ensure that the team avoids group think and all options are equally evaluated" (Bruce Power, n.d., p. 3). The checklist also asks, "Do all personnel on the ODM team support the decision? Do personnel who will execute the plan support it?" (idem).

The final part of the ODM process is to develop a plan to implement the decision. The checklist prompts that the plan needs to address adequate documentation, clear roles and responsibilities, contingency plans and resources. When the ODM team is happy that they have followed the process and have developed a path forward, the completed ODM form is taken to the Operations Manager for his or her acceptance or rejection.

The ODM procedure establishes that, even in an ambiguous or uncertain situation, then being 'in the process' is the expected place to be. Thus, even though there is no pre-determined procedure for the specific issue, a pre-determined approach is expected to be used to manage the issue. This expectation is encouraged by senior leaders as described by a SM, "*the Plant Manager and the Vice President regularly, in an open forum, say 'what process are you going to be in?*' SM3. The advantage of this was explained by another SM, "*We all know where we stand if we are inside a managed process*" SM4. This also contributes to a level of 'comfort' that was mentioned by several interviewees.

> "*I know we have the rigor, we have the process, the framework that gets us into process when we don't have a process. It gets us into someplace [that is] a comfort in some ways. It brings down the level of anxiety because an ODM is [required] because we are in an emergent situation and we need to make a decision*" EN2.

The four parts of the ODM process, as outlined in the procedure mirror very closely the typical, ubiquitous, decision making steps in any conventional managerial textbook, i.e. define the problem, identify possible solutions, evaluate possible solutions and finally choose an option (Hayes, 2013). This suggests that the premise for success in ODM is based on a process of rational choice. This leads to the need to identify credible options and make a correct assessment of each option. The procedure sets some high level standards for acceptable recommendations, for example, "decisions are based on a full understanding of short and long term risk" (p. 4). Even though this type of guidance is very subjective and the effective application of the process still depends heavily on the experience and judgement of the participants, the rational approach suggests that the ODM process is mostly aligned with the existing philosophy of control.

The ODM team

A multi-disciplinary ODM team will be formed to address the ODM issue. The ODM team must include, as a minimum, a representative from Operations, a representative from Engineering, and a 'Nuclear Safety Culture Advocate'. The advocate role is also commonly referred to as the 'black-hat'. The team leader is assigned by the OM and is always a qualified SM, who will also act as the operations representative. Additional team members will be assigned depending on the team leaders judgement of the skills and experience required to address the issue.

The 'Nuclear Safety Culture advocate' has a specific role assigned to help the team avoid 'groupthink'. "This person shall remain independent from the decision process, and will challenge the recommendations and rationale …" (Bruce Power, 2011, p. 8). This person is typically referred to as the 'black-hat'. This role can be filled by another SM, or can be filled by a Nuclear Safety Advisor. In addition to help avoiding groupthink, the black hat is expected to challenge anything that does not comply with,

-Operate conservatively
-Do not relax rules in times of crisis
-Maintain defense in depth
-Verify actions affecting reactor safety
-If in doubt, stop and ask
-Ensure all actions stand up to critical scrutiny
-Understand the implications of any change
-Do not live with problems
-Determine and correct underlying reasons for problems
-Keep it simple (Bruce Power, 2011 p. 8)

Lastly, ODM teams usually include a 'Nuclear Safety Advisor'. The nuclear safety advisor role is a function within engineering that specialises in the SOE. The SOE forms a large body of knowledge and is difficult for any one person to be familiar with the whole. For day-to-day operations the required operational limits, along with any required margins, are embedded in the plant operational procedures that are used by the operations staff to operate the plant. However, in cases where there is no procedure it is important to establish what SOE limits apply and where, if any, margin exists. The NS advisor provides a first level of support, and will request specialist support as required to help.

The mandated formation of a team to address an ODM issue suggests that there is value expected from social interaction to augment the rational approach to decision making. The procedure refers to a multi-discipline team being formed, and as a minimum mandates three types of expertise to be involved. The ODM team leader is a qualified SM who has broad expertise in the overall operation of the plant. A NS advisor who brings expertise in the overall safe operating envelope of the plant typically fills the 'black hat' role. The team is then supplemented with engineering expertise that is of much greater depth but more focussed in specialist areas.

The membership of the team is also further defined by the specific expertise added to the team based on the team leaders preliminary analysis of the ODM issue. The team leader will add additional expertise based on the need to address the technical issues that are anticipated. It is also true that expertise can be added if, during the ODM team deliberations they find they need additional expertise. However, a team built based on what is 'needed' to solve a specific problem cannot be said to be a truly diverse team. This lack of diversity is balanced, to some extent, by the mandatory inclusion of an Operations representative, and a representative from Nuclear Safety, both of who have expertise that is broad across the plant, as opposed to the narrow but deep expertise of engineering. But this expertise is primarily technical in nature. As such the team formation is influenced heavily by an analytic approach. A diverse team may have a different mix. For example, one manager speculated that ODMs could perhaps be improved by the inclusion of a facilitator, or by the inclusion of a HR performance or leadership trainer. Also, a diverse team membership would be defined by the nature of the 'system' rather than by the nature of the specific 'issue' being addressed.

The procedure identifies groupthink as a potential issue with group problem solving. However the procedure gives no specific guidance on how to avoid groupthink. The written guidance for the black hat can be characterised as assuring compliance to standards and verifying recommendations meet existing requirements. It appears that the procedure sets up the 'black hat' as an oversight function. The term 'oversight' is used in nuclear power to describe the observation of activity to establish if the work is being completed to the required standard. This also suggests adherence to the prevalent reductionist approach to problem solving. It does not appear that the 'black hat' is instructed to stimulate new arguments by behaving in a 'devils advocate'[2] fashion when he or she is being asked to remain independent of the discussion, as opposed to being asked to be intrusive in the discussion.

The attributes of ODM participants

The definition of ODM also includes "… attributes employed by personnel …" (Bruce Power, 2011, p. 2). These attributes are included to define how ODM participants, and in some cases, all facility staff, think and behave towards the process. All facility personnel are expected to,

> Be vigilant and promptly report potential threats to personal safety or safe, reliable operations … [and] exercise a questioning attitude. Do not hesitate to challenge proposed actions if they do not appear to adequately address the objective of safe, reliable plant operation (p.12).

Exercising a 'questioning attitude' is emphasised in several places in the procedure. The procedure encourages all ODM participants to "freely express opinions and counter arguments. They must not hesitate to give dissenting views" (p. 8). Finally, when considering adverse outcomes, "always consider what the worst case scenario might be … avoid discrediting facts that do not support a preferred outcome … [and] beware of technical arrogance i.e. over reliance on past successes, failure to consider external opinions" (p.7)

The attributes appear to provide motivational guidance to the participants in the ODM process with the implication that the ODM process will be successful provided that the participants are thorough and attentive to every detail, and are prepared to challenge anything they believe to be unsafe. Inclusion of these elements in the ODM procedure suggests that control of the human behaviours is thought necessary for successful outcomes, which in turn suggests a continuation of the philosophy of control. Conversely it can also be seen that an objective of the procedure writer is to help create an environment where anyone can talk of his or her concerns freely, especially in the face of an emerging situation. However, it remains an individual responsibility to raise issues and concerns, rather than perhaps, defining 'free speech' as an attribute of the social process being expected in the ODM meeting.

Operational Decision Making in practice

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[2] A dictionary definition of devils advocate is "a person who supports an opposing or unpopular view in order to promote argument or discussion"(Barber, 2004, p.413).

Initiating the ODM process.

The first step is deciding whether an issue should be handled by use of the ODM process. One shift manager described the threshold for using the ODM process as, "*We are in grey territory, where we are outside procedure and there is perceived risk but we don't fully understand the risk or we don't have enough information to make an informed decision*" SM3. The very first step in the ODM process still relies on the judgement of experienced staff. An operations manager stated,

> "*there are three criteria [to initiate an ODM] but it is still subject to experience and judgement. [Persons involved in this type of decision] must have an understanding of the bigger operating picture… We do rely on the team, not just one person. No one is ever alone when facing uncertainty here. ODMs are started based on front line monitoring. Field and engineering staff make suggestions*"OM1.

Conversely, not initiating the ODM process when it should be utilised can result in making some situations worse. A few years ago, "*the duty crew attempted to troubleshoot [a leaking valve] on their own. In the process they created a bigger leak that they were not prepared to deal with. They had not thought through the possible consequences / outcomes*" OM1. A SM also mentioned this event,

> "*[The] decision [was]made in real time, and, as discussed with the crew afterwards, the duty SM, there was no pressure to do it that day. We could have stopped and consulted but we didn't. Nobody had any hint that anything would go bad*" SM4.

The SM reflected about this incident, which happened to another crew,

> "*how do you watch your self and the situation; have the situation awareness conceptually to put yourself in a space and say, I think I might be wandering into knowledge based mode here, and are there consequences with that that I need to address more formally*" SM4.

Given that judgement has to be applied, the plant management teams do reflect upon where they set the threshold for initiation of ODMs. Initiating unnecessary ODMs by being 'over-sensitive' is a waste of resources and reduces confidence in the judgement of the leadership. However it is also incumbent on front line operations managers to actually recognise that a given situation requires an ODM approach to safely manage the path forward. The difficulty of the intervention decision gives an indication of the complexity of the operations environment. In response to this uncertainty SMs are being actively encouraged by senior plant managers to initiate an ODM anytime doubt arises about a new risk or a path forward. As long as the issue is developing slowly enough "*the duty crew are expected to initiate getting the [ODM] team together*" OM1. The Operation Managers are more focussed on encouraging the use of the process than any concern about it being overused.

The ODM process is intended to help operations managers address emerging issues by providing instructions to enact a process. This implicitly acknowledges that the operations environment is not fully characterised by the existing procedural guidance and can be seen as a vehicle to support the 'real-time' logics of plant managers. Even though the ODM procedure is written in a format similar to other operating instructions, with entry criteria dictating when the procedure is appropriate, the operations managers are still faced with the ongoing challenge of recognising potential ODM events, and then making an accurate assessment of the need to follow the ODM process. The organisation leadership does acknowledge the uncertainty by continuing to ask about plant conditions, and by encouraging the use of the ODM process when any doubt arises. The ODM process is thus established at the nexus of the procedurally controlled system and that part of the system which is not yet included in the set of defined procedural instructions.

Time pressure

The use of the ODM process takes time. However plant management are reinforcing that the process should be used even if it takes longer to make a decision.

> "*Any time pressure is set by the plant and not by the organisation. We rarely put time pressure on a person. It is usually self-perceived. So if the plant is deteriorating quickly, there is no time to get a team, then the duty crew has to handle it. The duty crew will make the call. If the issue is slower, then they are expected to initiate getting the [ODM] team together.*" OM1.

This was confirmed by a SM interviewee,

> "*for many years … the operations line [management] ... has been very clear that if you have an issue on the table don't proceed, if its safe to be where you are, until you are sure you have the information you need and you have a rationale that is sound for choosing direction A or direction B. It doesn't relieve the pressure entirely when you are in a real time situation with a variety of paths that may be available to you, [but] there is actually, other than the self-imposed pressure, nothing to say I have to act quickly. I actually have a mandate, and indeed my role as a shift manager or as an informal leader in my role on days, my role is to model those behaviours*" SM4.

Even in the case of commercial pressure the ODM process is encouraged. An OM mentioned an example where the issue of concern had resulted in stopping critical path work during a major outage. In spite of adversely affecting the outage schedule "*the emphasis was on focus on the safety issues, and focus on getting it right before we proceeded. There were no 'hours lost' questions to the team while they were working on the issue*"OM1.

In some situations, due to the rate of progression of the issue, the duty SM will establish their own limit based on their judgement of the situation, even though they have initiated the ODM process. As an example, when faced by a steam leak that was getting worse the duty SM was unsure that he would get engineering advice in time. "*The SM says, OK, I'm going to make up the rules. In the absence of engineering giving me a rule I'm going to set my own standard and that's going to be if the rate of condensate collection doubles in 3 hours, I am going to take the unit off line*" SM3. This value was chosen using best judgement, but the SM considerations included what would be required to manage the leak, and the length of time it would take to cool down that area of the plant. This is an example of the 'line-in-the-sand' approach (Hayes, 2012). However interviewees indicated that this type of scenario is relatively rare in the current utility operating experience.

The influence of time-pressure is usually discussed in terms of external pressure arising from the emerging issue itself, or the need to maintain production in a business environment. Several interviewees did mention the tendency for people to try to jump to a solution and fix the problem quickly. One SM commented " *the biggest problem was the sense of urgency and trying to slow it down … one person wanted to …[immediately] start to manipulate valves*" SM1, when describing his crews initial reaction to an emerging issue. Another SM referred to *"… the natural human tendency to rush to a solution which may or may not work*" SM4. An engineering manager commented that the initial stages of problem solving "*seems [like] a barrage of information … and it can lead folks off to jumping to solutions*". Adding a possible explanation "*I don't know if its engineers or whatever it is. We want to come running out the door within an hour and say 'go do that'. You have to hold everybody back and say here's a pathway to the solution*" EN1. The perception of time pressure can be seen to arisen from internal motivational factors, as well as the external pressures. Interviewees mentioned that the stop and consult expectation of the ODM process was just as important to manage this internal pressure as it was to manage external pressures.

This discussion of time pressure helps to emphasise the importance of the main ODM themes which are stop, consult, and use a structured process to decide a path forward. It is rare that operations staff has to make a quick decision on an emerging issue. At the simplest level the taking of time to approach a problem helps to eliminate the risks of well-intentioned quick fixes, which have not had full consideration of all possible outcomes. The management of time pressure also gives time to enact the consultative, or social, form of decision-making that is required by the ODM process. This consumption of time can result in pressure on both individuals and the business. It is clear from the interviewees that senior managers encourage a conservative approach when faced with uncertainty, and support this use of time in the face of business pressure. The commercial pressure is always present, but the impact is justified by the timely and diligent implementation of the organisationally approved ODM process.

Organisational evidence from the ODM meeting

Once a decision is made to initiate an ODM the OM will appoint a SM qualified individual to lead the ODM team. The SM is a natural choice for leading the ODM team. The SM role is a key position with a significant level of authority and SMs receive extensive training during their qualification process. The SM has extensive knowledge and experience with overall integrated station operation, and then a basic understanding of the fundamentals of each system element. This contrasts with the other participants who are more specialised in their expertise.

> "*The engineering folks can really talk to the very specific piece in a lot of detail but cant always relate what does that mean for the overall integrated risk or what is that for integrated operation. The other folks that have certification training / experience you can see that, based on the questions they are asking, … what is the risk of continued operation?*" OM2.

It is possible that the organisational authority of the SM could introduce bias while providing leadership. One interviewee explained:

> "*It is usual that … the operations guy is looked towards … the others are at a disadvantage [because] they know specifics about the component or system, but not the bigger picture. The ops guy is probably the one guy there who knows the most about operations combined with a bit about the engineering and a bit of reactor safety. But each of the other two is more specialist in their particular area*" SM2.

In spite of the organisational authority of the SM, the discussion remains free and open and, "*while there are dominant personalities [referring to a 'typical' SM] it is not dominant in the way of imposing their will on anyone else*" SM2. This is confirmed by a non-SM interviewee:

> *"[A] good thing is you will have the SM there, many years experience under his belt, you will have ANOs there, fairly experienced people, maintenance guys who are very experienced, but scattered in there you may have engineers with only a year from university, and maybe have a fuel and physics specialist … I've always found in ODMs that there is always great respect shown for everyone in the room … there is no authority being used in*

> *terms of the SM ruling the roost by the fact that he is the senior guy. Everybody has his or her say, everybody is treated as an equal, and everybody's opinion is respected. I've seen that in every ODM I have been to. I have never had any concern that someone is keeping quiet because they are scared to speak up*" NS4.

This evidence suggests that the participants in the ODM process work in an environment in which the authority gradient is minimised. The ODM team leader may have ideas about potential recommendations when entering the meeting but the evidence shows he or she will not use organisational authority to drive a particular outcome in the ODM process.

The first step in the ODM process is to describe the operational issue as accurately and concisely as possible. This step also serves the function of bringing everyone on the team to the same place in the current understanding of the issue.

> "*I usually have the engineering folks, because they have prepared the evaluation, and they are best placed to run through it. They lay out the description of the issue. Then, after they have done that I'll discuss the operational impacts … after that people will ask questions to get a common understanding, then we will move into potential decisions. At that point it is pretty much an open floor for people to propose potential choices*"SM2.

The initial discussion of the issue thus relies heavily on the engineering expertise. Several interviewees mentioned that there is a lot of respect for expertise at the ODM table, but as stated by one interviewee, "*the danger there is that if everyone is in awe of the expert you can accept what they say at face value. But the process works if you follow the questioning attitude… it drives you to ask questions to validate …*" EN2. For deeply technical issues the expert can expect to be questioned and challenged as the others in the team come to an understanding of the position of the expert. This is not seen as an attack on the capability of the expert, but as part of a culture that seeks to fully understand.

> "*People that are brought to the table are experienced ... recognised that they are highly competent in their area. At the same time we are all human and can make mistakes. It is free and open environment to ask and challenge, in a positive way. Following that approach you build confidence in the positions being presented. Questions are asked to clarify… and make sure I understand what the expert is saying*" EN2.

It is also possible that ODM team members raise issues based on intuition or gut-feel. Interviewees mentioned it is an important part the ODM process to not leave a doubt or concern un-addressed. An operations manager stated his expectation that, "*everybody has a right to speak up and if their gut-feel is not right we have to stop to satisfy and understand it more. If one person voices a concern it is possible that others may share similar concerns*"OM2. An engineering manager also confirmed, "*you have a right to question things … there is no such thing as a stupid question. Say it. We will listen to it and answer it. It establishes a right for you, especially a new person or a more timid person.*" EN1. ODM groups do feel obligated to help the individual understand why they feel that way, and help them to flush out the root of the concerns. "*Its kind of like a jury … if one person is not comfortable you have to let that person talk about it and listen to what they are telling you and then rationalise is there some way we can deal with their concerns*" SM3. Several interviewees were aware of cases where, for example, an experienced operator was just not comfortable in using a piece of degraded equipment even though it was considered nominally serviceable. In this case the ODM team supported this operator and recommended taking the equipment out of service rather than use the degraded equipment for a further time period. However two of the interviewees mentioned that an issue based on gut-feel may get treated differently depending on who is raising it.

> "*Gut-feel has to be weighed by the experience that informs it. A less experienced person would have less weight than a more experienced person*" NS3. A SM commented, "*I would say it depends on who is raising it… if it is someone that you have a lot of respect for it carries more weight … some peoples concerns I would listen to more carefully. Again it is subject matter dependent. There are some people, who have more of a tendency to be extremely black and white, or rule based, or who have more of a tendency to cry fire in a crowded theatre. Those people you can't discount their input … the nice thing about a public meeting is you cant actually ignore someone … Even if its an off the wall question … ask where they are coming from, then look into it more … not a bad thing and not unusual to have it happen*" SM4.

It can be seen that different sources of expertise, whether it resides with an acknowledged specialist, or whether it arises from intuition of an experienced person, have status within the ODM meeting environment. Even though the expertise of a specialist is highly respected, the evidence shows that participants in the ODM process also see value in addressing gut-feel concerns that do not have an associated 'technical authority'. In addition, it is acceptable for the 'word' of the expert to be challenged during the discussion. Overall it appears that the environment of the ODM team meeting is such that any expertise hierarchy is reduced. However, there still seems a consensus among the interviewees that points to a preference for information which is judged to have a valid (technical) basis rather than based on the intuition of a team member.

When considering the overarching philosophy of control within nuclear power the clear definition of authority is part of the 'command and control' approach. Also the status of expertise is important within the notion of 'calculated logics' (Perin, 2005). It could therefore be expected that these dimensions of a control framework would be continued within the ODM process. However it appears the ODM environment has, to some degree, balanced the gradients of authority and expertise. This in turn creates a forum that supports a group of diverse expertise to have open discussion and create common understanding of an emerging issue that is affecting the 'system' in some way. Thus it appears, at least at the outset of consideration of a new ODM issue, that the participants have some freedom to consider different ideas and possibilities that are outside of the currently understood procedural framework. This provides opportunity to address the issue that, "in a complex system, there is no objective way to determine whose view is right and whose view is wrong, since the agents effectively live in different environments" (Dekker, 2011, p. 200)

Discussion and selection of options

The second step of the ODM process is to generate and study options of possible ways to deal with the subject issue. There is always a 'remove from service' option and a 'do-nothing' option, which define the range of possible recommendations. Removing the affected equipment from service can usually eliminate the issue but this may result in a complete shutdown of the affected generating unit. This action will resolve the issue, but commercial impacts will be felt by the organisation. Alternatively the 'do-nothing' option may result in a slow degradation that will eventually turn into failure at some point. It may be difficult to pre-determine exactly when a failure would occur, or it may be that the failure could result in an operational transient where the operators have to react to the plant disturbance. Between the two extremes other options are developed which will provide a prudent course of action, which minimises risk, and which does not cause significant business impact. In many cases options will be presented as part of a formal engineering evaluation that has been completed as an input to the ODM meeting.

"*Implicitly it's a 'pro and con' kind of approach. By listing initiating events and deciding which ones we felt we needed to cater to and represent a minimal challenge to the operations staff in the control room. Which one do we care about the most?*" SM4.

The practical implementation of each option is an important part of the discussion. This focuses on the ability to see where an issue is getting worse (early warning), and to be able to take corrective action or shutdown to maintain full control and certainly before any damage occurs.

"…there was quite a bit of discussion about potential consequences… what was the worst thing that could go wrong … basically we, as a group with all the disciplines, we agreed what the worst case is so that we [can determine] we actually have control so that we can mitigate anything that can go wrong" NS2.

Ultimately, if there is no confidence in the ability to monitor and respond, then the ODM team will recommend taking the equipment out of service, regardless of the business impact. This will also apply where the extent of the degradation is too great for continued operation. For options that remain under discussion the ODM team assess the relative merits of each remaining option. Quantitative information is rarely available and the discussion follows a pattern similar to the one described by an engineering manager:

"*We could not get to a number in terms of this is our probability that we are not going to have an issue. But more based on current condition of equipment, what we are able to monitor, and how quickly can we take action if we see a problem. What limits are we going to set on monitoring of parameters versus the limits we know we can handle? It was really an assessment of the ability to manage consequence if things go wrong. That part of the risk equation[3]. The probability we believe is low and we couldn't get a number on probability, but we understand the consequence would be to each piece of equipment. And these are the barriers we put in place to prevent that consequence from being realised. So out of that comes an acceptable risk level … I rely on my understanding of the health of the equipment, my understanding of the design, and the [current] situation and then, from that assessment, and we do have experience of how systems operate, we understand how the systems react, you can make an assessment of your starting point of risk. Then you can walk your way through all the potential scenarios you can think of that could go wrong and then assess whether we believe we have a credible way to mitigate the impact of that assessment. And then it is the cumulative effect of all these potential scenarios. To get all the credible scenarios, that's why you need to bring in various perspectives... different people that come from a different perspective. You walk your way through each challenges… is there something we missed? Then at the end you do an assessment on whether you believe the risk is acceptable…. if we got it wrong how do we assure ourselves that there is an acceptable way to mitigate it?*" EN2.

It can be seen that the options considered are generated from knowledge and experience of the ODM participants based on their assessment of what can go wrong and the consequence associated with each scenario. The multi-discipline nature of the group discussion helps to identify as many scenarios as possible. Then, rather than considering the probability of each scenario the focus of the discussion is based on whether the group feels that each consequence can be managed such that operating limits are not exceeded, and that the consequence can be realistically detected and managed by the operating crews. This focus on the practical implementation rather than on more abstract 'risk assessment' methodologies has been noted in previous research (Hayes, 2012, 2013). Ultimately the judgement on whether any preferred option is safe is based on an assessment of the practicality and

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[3] The generic risk equation referred to is Risk=Probability x Consequence

of the effectiveness of the proposed barriers. "For the purposes of operational decision-making this approach allows managers to assume that, provided all safety barriers are in place, then the system is safe" (Hayes, 2013, p. 137).

This reliance on barriers appears to be a result of the influence of the notion of 'calculated logics' (Perin, 2005). However the ODM procedure does encourage looking at each option in terms of the integrated plant operation and considering the 'aggregate effects' of any option in combination with, for example, other deficiencies in the plant (Bruce Power, 2011). This broader view can be considered a more 'system' based view of each option. This is also used both to help identify the most appropriate option, but also as an input to development of monitoring plans and contingency plans for use by operating crews during the plant implementation of an approved ODM recommendation. It is also implicitly assumed that any implementation plan will need to be carefully monitored during execution due to the difficulty of predicting every eventuality. As such it appears that the rational approach to identifying consequences, and formulating barriers to each consequence, is supplemented with a more 'system-based' consideration.

The ODM meeting process may possibly inhibit a free discourse on the subject issue due to the meeting being seen as 'making a choice between recommendations'. The interviewees all stressed that the ODM meeting is a decision forum. The recommendations are developed using the engineering evaluation process and the resulting evaluation is presented to the ODM forum. This effectively takes some of the attention paid to the issue into a different forum, which may not have the social advantages of the ODM process. However it is usually the case that the engineers involved in the evaluation process do also attend the ODM. In spite of best efforts to prepare for an ODM meeting, it sometimes happens that the group dynamics show that they need to collect more information or study the proposed options further.

> "*We have had some [ODMs] where we went in with the [recommended] decision and determined that we didn't think we had enough information after all, and we said we are not going to pursue it further. … If you had engineering or operations break into mini-brainstorming and then you hear things that you haven't heard before. Then you have the sense that we are not prepared to hold this thing any more because other ideas are coming out and they need to be pursued in another forum. The ODM is not for brainstorming and saying 'maybe we should do this instead? It is not for that. You come to the meeting having already thought about the potential alternatives and they have all had some rationalisation. There are discussions about the rationale for certain decisions but not bringing in new information*" SM3.

In another example "*there are questions that are asked, and if there is agreement that we don't have all the facts there is an action taken to go, and we are not going progress, until we have the answer come back with validated facts*" EN2. This evidence suggests that the ODM process is positioned as a 'decision making' forum and that new data which emerges is moved elsewhere to be pre-rationalised before being considered again in the ODM forum.

It is certainly important that any recommendation from the ODM team will have been rigorously reviewed prior to being approved for use in the nuclear plant. However it seems to suggest that 'discovery' activity such as the collection and interpretation of data, and the brainstorming of ideas, is displaced elsewhere. This may undermine the synergy of the ODM forum in identifying new issues of importance. For example, raw data may have different meanings to different meeting participants. The focus on the verification of facts may lose broader interpretation of meaning in the data. For example, if erroneous data does exist, then why is it visible to the agents within the system? The erroneous data may be excluded during the fact verification process for this event, but what does their existence mean for the broader operation of the system and the interaction with future events? One OM did raise the rhetorical question "*why do we have separate engineering evaluations and ODMs?*" OM2. He then went on to say that it was likely due to the sheer size of the engineering support organisation and was a way of clarifying the interface responsibilities between the engineering organisation and the operations organisation. The focus on control by process adherence may therefore limit the potential for the discovery of data and the translation to verified facts may become disjointed by the procedural (and organisational) separation of the ODM process, and any supporting engineering evaluation or troubleshooting process.

Once the group is ready to make a recommendation the ODM leader will go 'round-the-room' and ask everyone individually if they have any objections. One SM identified that he knows when the group is ready to make a recommendation because the "*debate on the topic and the vigour dies down. The group is no longer asking questions*" SM3. At this point the leader completes the ODM form as the official record of the ODM discussion. The form has space for a written description of the issue, a written evaluation of potential decisions, the recommended decision and rationale, and the implementation plan. The form also contains three, yes/no checklists that the group review together. The form also includes the names of all present at the ODM meeting. This form is then taken to the Operations Manager for discussion and acceptance.

The recommendation of the ODM team is presented to the Operations Manager for approval. In assessing the output of the ODM process one Operations Manager describes how he completes his review,

> "*The ODM team leader sends me the final copy of the checklist to review. I then discuss, usually face to face, the ODM process with the leader, how it went, any big issues or sticking points. This is an opportunity to ask lots of questions and is a part of the final ODM product. Did they capture the problem correctly? Does it answer the right question? Look at what was considered. Usually at least three options, including a 'do-nothing'. I look at the pro/con analysis. I look at who was on the team. Was it the right cross section? Were they knowledgeable? Review for overall completeness. Look at the actions that would be required if I approve the decision. What is the plan? Does it make sense? Will it just mitigate a poor condition, or will it improve the condition*?" OM1.

The OM is not involved directly in the deliberations of the ODM team and relies on the ODM team leader to brief him on details of the discussion. The approval process includes a review of the 'technical content' of the recommendation, and a review that the 'process' has been followed in a credible way. The OM has the option of rejecting the recommendation if his or her personal review reveals any concerns. If the ODM is approved then operations staff, along with any required support staff, will enact the defined action plan.

The output from the ODM process requires the authority of the OM to be accepted for implementation in the physical plant. In applying that authority the OMs do make use of their own extensive knowledge and experience base in plant operations to review what is being recommended. However they also review the execution of the ODM process as part of the approval process. It is recognised that the quality of the recommendation depends on the process as well as the full assessment of the 'technical' issue.

The ODM forms, and any supporting engineering evaluations are kept in a database. A review of the forms associated with the events discussed in the interviews revealed a brief summary about the issue and how the preferred option was selected. Usually the options considered were listed with a 'bullet' format list of pros and cons. The chosen recommendation and the rationale were stated briefly, along with a list of actions required to support implementation of the decision. The forms do not show any detail of the discussion or, for example, the issues based on gut feel or intuition. As an OM explained, "*[these sort of issues] show up in the team work but not in the documentation. The team works to address the issues raised so that they can be resolved to the satisfaction of the individual, and also the satisfaction of the team… I then discuss, usually face-to-face, the ODM process with the team leader, how it went, and if there were any big issues or sticking points*" OM1.

There is also evidence of a hierarchy in the value of the written record associated with the ODM process. To illustrate this point, engineering evaluations are presented in a full written memo format with all assumptions and judgement clearly identified. The output of the ODM process is summarised on a form with a checklist. Perin also found:

> The two logics [calculated logics and real time logics] are documented differently. Explicit rationales accompany calculated logics on the nuclear side, based on reliability metrics of the structures, systems and components of the reactor unit … The rationale for real-time logics appear mainly in conversations …But as things stand, industry experts and station managers understand these logics less as a partnership than as a hierarchy (2005, p. 199-200).

It is possible that some issues raised in the ODM meeting will not be recorded if they are resolved to the satisfaction of the team prior to making a recommendation. This suggests that 'concerns' have less value than 'facts'. As they are then not included in the records, these concerns will not be visible to staff in the future and hence may not be raised again under different conditions. There appears to be more value placed on a comprehensive record of the engineering work when compared with the record of the ODM process.

The discussion of options is at the core of the ODM process. The value of a multi-discipline team is apparent as they gather information, review possible options and identify potential consequences associated with each option. The process does include a consideration of system-based elements such as the aggregate plant status, when considering how an adverse scenario may develop. The process also requires that any recommendation will include a monitoring plan to recognise when an adverse situation is developing and have a credible contingency plan. These items are all items which are included by Dekker in his discussion on coping with the aftermath of events in complex systems (Dekker, 2011). In the case of ODM, these items are all being considered proactively.

However the process is also influenced by the expectation that the discussion should focus on pre-rationalised options, for which the basic facts have already been verified. This emphasis on controlling and organising the decision process may make it more difficult to build understanding of an emerging issue by moving the process of discovery to another forum. This in turn makes it more difficult to assess the meaning of the information being made available about the issue in question.

The 'Black Hat'

All interviewees expressed that 'groupthink' was a phenomena of concern when involved in ODM process and all expressed that the 'black hat' was the key role designed to counter groupthink behaviour. One interviewee explained groupthink in terms of "*defaulting to what everyone else is doing because if they are all doing it, it must be ok*" NS3. Another interviewee mentioned,

> "*… it is human nature to develop a stronger level of comfort with a decision if you have people, who are at similar or more levels of knowledge or experience that you have, reaching the same conclusion… People coming together who may have the same outcome in mind would be able to incorrectly influence each other. There is a lot of comfort in having others make a decision with you… it could be competing with your objectivity*" NS1.

However when describing the black-hat function most interviewees identified that the role was to act as a cold body reviewer and attempt to identify things that had been missed by the group as a whole.

> "*The ODM process has the 'black hat' role. That is the one thing that is different to any of our other decision-making processes that we have a person who is not supposed to get involved in the detailed discussion. They sit back take it all in and provide oversight on the process and the depth of the process and the interactions of the people. Oversight is what it is about*" NS4.

> "*A feature of the ODM process is the black hat … listening to the discussion but not participating per se, maintaining an objective distance and listening to the discussion and the conclusions that are being reached. And when you go around the room at the end of the meeting you save the black hat for the end. What do you think? Do you have any concerns or questions or is there anything we have missed?*" SM4.

Only one interviewee referred to the black-hat role with the term 'devils advocate'. The intent of the 'black hat' role is similar to the ubiquitous term 'devil's advocate'.

> "*[The black-hat] has useful knowledge to evaluate if they get the impression people are going down the wrong path for whatever reason, be it technically, or just the way a herd goes down one train of thought. Especially if there is a strong leader in the group, who is a good leader but not a good operational decision maker… They will play devils advocate. If everyone seems happy that something will never happen they might challenge it and take it one level deeper. Or do we really we have the technical expertise here to definitively say that or is that your pre-conceived notion? … Are people really looking at the worst thing that can happen and do we really understand how likely it is to occur*?" NS1.

This description is more in line with a dictionary definition which is "a person who supports an opposing or unpopular view in order to promote argument or discussion" (Barber, 2004, p.413).

However, it appears that the 'black hat' is usually positioned more as a verifier, that is, someone who reviews work for completeness and correctness. In one case an interviewee expressed that it was an option to "*have somebody sit down and review the information I am going to send them. Essentially do an independent verification [of the ODM recommendation]*" SM4. The ODM procedure implies the black-hat provides oversight by monitoring of standards that need to be maintained during the process. Monitoring and reinforcing standards is actually a management and supervisory function. Verification and oversight are both practices that are firmly entrenched in the control philosophy.

The role of a black hat can actually add value beyond that discussed so far. A black-hat working in the style of the ubiquitous devil's advocate would be very much more interactive throughout the meeting, taking contrary views, asking for deeper explanations, looking for adverse interactions. A black hat who is thus engaged could also ensure the social factors are monitored, challenging a quiet participant, or demanding an answer to an issue that has not been addressed. When imagining the black hat function in this way it is only a short step to see how this role might trigger new discussion and identify new issues to be addressed, particularly by challenging any commonly held assumptions, or by exposing unnoticed interactive relationships.

A devil's advocate would also help to address a concern that one interviewee raised that persons who bring a narrow field of expertise to the ODM meeting may have difficulty communicating with experts in other fields. "*You can have [for example] a chemist who is so focussed, 'I deal with chemistry'… people will draw boundaries that I don't want to get out of my comfort zone, e.g. chemistry. So that does come into play and you have to watch for it. You have to force the discussion to happen*" SM1. The 'delivery' of expertise was of concern to another interviewee when explaining that, even though engineering advice is highly valued, the acceptance could be affected by the capability of the engineer as a presenter.

> "*We have quite a spectrum of communicators. You could have someone who is highly technically knowledgeable but communicates poorly, so the quality of their information may be quite high, but how is that internalised by the rest of the group? They may give that less value. Whereas we may have a less knowledgeable but more charismatic compelling speaker. They may inappropriately accept that advice with a higher level of contribution to the discussion… [To counter this] we will apply the black-hat in the room*" EN3.

The role of the black hat has been described in three different ways, the verifier, the oversight person, or the 'devil's advocate'. The first two are a continuation of the control-based philosophy. In contrast, the less familiar devil's advocate role has potential to help reveal new information. It seems there is opportunity for the utility to examine its expectations of this role. Ultimately the question for the ODM process is, do we know everything we don't know versus double-checking everything we do know? This again raises the concern that a focus on gathering and verifying facts may result in important data being missed. It could be suggested that the black-hat function be focussed on discovery, and the roles of verification and oversight be completed by supervisors or by oversight personnel.

The value of Operational Decision Making

In practice operations managers are faced with an ongoing stream of daily decisions to manage the plant and the associated activity to operate and maintain the facility. Even though the ODM process is not used for every decision, it is clear that the plant managers have to deal with an ongoing range of issues that are not clearly addressed by the procedures. Hence the evidence shows that the real-time logics discussed by Perin (2005) are still an important part of the daily life of operations managers in 2013.

When talking about the overall ODM process some interviewees mentioned the challenge of making judgements on issues that do not have clear black and white answers. "*There is no real proof afterwards that your decision was the best one ... but I've yet to see an example of an ODM completed where the recommended decision was taken and it blew up in our face*" SM2. All interviewees stated that they believed that the ODM process has helped them to manage emerging issues better, and they have not experienced an ODM where it led to making a situation worse. One OM stated, "*I'm quite satisfied [with the ODM process]. We've had very positive results from it. It doesn't mean that very decision we would like to do is supported through this process. There's been times where the decision is not to proceed*" OM2. "*It [ODM] is becoming part of our language. It appears to work well and has not led us to difficulty. It seems to help us deal with a broad range of issues*" OM1

They all expressed that stopping to consult, and using a structured approach to decide a path forward, was of great value in dealing with the large variety of issues that are experienced at the plant.

> "*One is always free to collaborate. Since the ODM process is really a formal collaboration tool as an antidote, or a preventative measure, to make sure we get out of knowledge mode cleanly. To reduce the probability of error from 1 in 2 to we hope something more like 1 in 1000. I don't know what we are reducing to, but really like the collaborate concept for knowledge based mode. It gives you a multi discipline, you've got friends, who can all go in this together and talk it through, ensuring that we understand all the facets of a problems before we propose a solution*" SM4.

One interviewee summarised the ODM process as,

> "*our obligation running the nuclear industry is to demonstrate we are making decisions that manage our margin and manage the level of risk that we are incurring. The 'demonstrate' has always meant to me in writing, fact based, auditable by an objective and knowledgeable third party. Demonstrate we thought about the risk. ODM leaves documentation about what we thought about*" SM4.

This description describes an important objective of nuclear power management very much in terms of the procedural based, written, control frameworks. However it also suggests that nuclear managers are thinking of the ODM process in that way also, as opposed to thinking of the ODM process as a means to think beyond their traditional framework.

CONCLUSIONS

The ODM process was chosen as a research topic to examine what nuclear managers do when they are faced with a situation for which they have no pre-determined procedure. This topic is of interest given that the nuclear power industry has significantly improved performance over the last 35 years using a philosophy of control. The control philosophy directs that most work within a nuclear facility is governed by pre-determined procedure. This approach to establishing safe operation has remained essentially unchanged over this period, even though the complexity of nuclear organisations has increased substantially. It has been suggested that the existing control approach may have reached its limits and that new ways of establishing safety are required to supplement the control approach. Inquiry into the ODM process therefore provides an opportunity to look closely at the region of activity for which the control philosophy has not defined an explicit response.

The interview format chosen to study ODM was very successful in eliciting data that could be used to develop a rich description of the ODM process. Taking each interviewee through multiple passes of an actual event allowed the 'as-lived' experience of the ODM process to be revealed. For example, the first pass through an event tended to be a very technical description along with the interviewee emphasising the key steps of the ODM process as described in the official procedure. The second pass encouraged the interviewee to discuss what they were thinking during the subject event, and how they were approaching the problem. The third pass encouraged the interviewee to reflect upon the social interactions and the mood and nature of the discussions. The data from each interview was then arranged around the core process of ODM to develop an aggregate view of the overall process. This aggregate view provided much more depth in the cognitive and social environment of the process without the distraction of the technical facts of each individual scenario. Indeed, it appears that this approach is of value when studying situations much closer to routine, normal, operations where the individual 'stories' of events may provide less insight than a consolidated picture of, for example, the overall ODM process.

The ODM process provides a generic approach that can be applied to a range of plant issues. The process described by the ODM procedure is straightforward and is described by interviewees as simply stop and consult, when faced with a unique emerging condition of concern for which there is no pre-established procedure! The overall objective of the process is to generate explicit instructions (i.e. an ad-hoc procedure) to address the issue of concern. In this way an emerging issue is brought back under the umbrella of the closely controlled procedural driven environment expected by the overarching control paradigm.

The ODM procedure instructs that a structured process be followed to determine a suitable path forward using a process of rational choice. This requires the identification and evaluation of credible options. A multi-disciplinary team enacts this process, and that team must have a designated 'black-hat' who will help guard against 'group-think' and monitor standards. The procedure also specifies personal attributes that are deemed important for success of the process. It is expected that the procedure be followed at any time it is believed the 'entry-conditions' are met. This procedure thus follows the same form as any other procedure in the plant documentation hierarchy, where instructions and responsibilities are specified to meet specific goals. The expectation is that the process will deliver a suitable recommendation to the OM provided that the process steps are followed, and that each team member applies a high level of rigour. The ODM process thus appears to be established as another 'rational' process within the framework of control, much like another 'tool' in the toolbox of the control regimen. This 'tool' is then used to address issues as they emerge.

As such, the ODM process exhibits some characteristics that continue to reinforce and legitimate the control paradigm. The procedure continues with a reductionist (or analytic) approach by defining the team membership based on the expertise required to address the perceived issue at hand. This approach assumes that the boundary of the issue is known in advance. The team may, as a result, not have the expertise required to recognise the full meaning of the data being presented for a unique situation in the context of the broader socio-technical system. There is heavy emphasis throughout the procedure to ensure that data is 'factual'. This establishes a hierarchy within the data that may eliminate useful information about the broader system. The ODM process relies on 'verification' to assure the quality of information being considered. Verification relies upon the expertise of the verifier and may be subject to limitations based on individual experience and the extent to which the system context is considered. The control paradigm characteristics described are key elements of traditional analytic problem solving and the ODM process is focussed on developing a rigorous plan to address the issue of concern. However, in the context of ODM in the complex environment of nuclear power operations, these characteristics may restrict the full appreciation of the data being presented within the system.

The ODM process also exhibits characteristics that move away from that expected within a philosophy of control. It appears that organisational authority and the respect for expertise appear to be balanced by a more egalitarian environment which supports the expectation that anyone has a right to say what they think, and raise their concerns, regardless of their individual background and rank. The revelation and discussion of potentially diverse mental models contrasts with the paradigm of 'control logics' where it is expected that "design basis, technical specifications, procedures and rules maintain control" (Perin, 2005, p. 198). Participants talk about their concerns and ideas and the basis for them, which then allows others to probe and critique the ideas, or further lever the idea within their own experience. Even though the ODM process still requires experienced participants to make judgements about the suitability and prudence of recommended courses of action, the ODM process provides a framework that encourages discourse and building of a common understanding about the issues at play. Diversity and respect for difference, the gathering of information, and the consideration of consequences, all support a stronger proactive response to emerging issues in a complex environment.

However, the ODM process may still inhibit full discourse on an ODM issue due to the ODM meeting being seen as a forum where a choice is made between pre-determined options. A separate engineering evaluation process generally verifies facts and provides the options, and the emergence of any new information, or the suggestion of a new option during the ODM meeting, would generally result in a 'time-out' to have the option studied outside the meeting. It appears that the prevalent control structure within the organisation expects all activities to be in the right procedural 'box'. This in turn may inhibit some of the synergistic advantages of discussion in an ODM forum.

The philosophy of control approach can be distilled to the maxim, 'follow the procedure'. The ODM process is, paradoxically, implemented by procedure to be followed in the unique event there is no procedure to cover an emerging situation. The following of this procedure gives somewhat underspecified guidance to the plant managers. The process as described is very subjective and it still requires the application of experience and judgement to develop and analyse options, and judge the merits over one option over another. Ultimately a judgement is made if the recommended option itself is acceptable for implementation in the plant. As such, the ODM procedure is the one procedure that tries to move beyond the industry's control regimen. It attempts to influence judgement in terms of its acknowledgement that ODM consists of both a process and a set of attributes employed by personnel. The attributes appear to urge the quality of personal interaction with the process by asking each person involved, for example, to have a questioning attitude, to freely express opinions and counterarguments, and, if in doubt then stop and ask. It appears that the procedure attempts to capture a complex social process in a technical format. When discussing this idea with one interviewee commented, "*I hadn't really thought of it that way, the way that procedure came through … but it's pretty much technically driven padded with some 'make it rigorous'*" OM2.

The acknowledgement that social factors may support good performance is difficult for a control paradigm. An assumption of the philosophy of control is that, "a peopled technology operating in the world is … a source of variability and instability to be minimized by maximising automation, standardization and training"(Perin, 2005, p. xii). In contrast the ODM process adds value by creating a social environment where experienced staff, with a mixture of expertise and background, can have a free and open discussion about the issue in question. To some extent, the ODM process is beginning to acknowledge and organise the real-time logics that front line managers use to address emerging issues. The process as designed works through the diligent application of a decision making process. The process as observed appears to add value by creation of a social environment which leverages experience and encourages sharing of ideas and concerns, and which in turn, engenders synergy between the participants to create a broader understanding of the issue, and a more comprehensive approach to address it.

The philosophy of control in nuclear power has historically provided a strong basis for the improvement of safety in nuclear power. The ODM process was originated and implemented within this framework of control and, according to the participants, has improved the organisation's response to emerging issues that may impact ongoing safe operation. On the other hand, artefacts from the philosophy of control, as outlined in this thesis, also act to inhibit the full value that could be derived from the ODM process. It can be seen that the ODM process can be improved by enhancing the diversity of the ODM team, by clarifying the difference between discovery and verification, and by refining the role of the black-hat. This will then enable the full discovery of data associated with the system operation and the emerging issue of concern, and it will also allow discussion of the meanings associated with the data. This will, in turn, provide a more comprehensive input for the processes of rationalisation and verification. Ultimately the output of the ODM process must still be translated into instructions for operating staff. Such instructions must be detailed, verified, and explicit so that operations staff responsible for the plant can maintain full control, and be fully aware of the safety constraints.

As understanding of the ODM process is developed it will be interesting to consider how the control philosophy will adjust as managers become more experienced at using the ODM process. Currently the ODM process is used to fill procedural gaps in the control mechanisms. However, the focus and encouragement to use the ODM process to address emerging issues could also be seen as the addition of a new methodology to supplement the control philosophy. Rather than seeing an emerging issue as a challenge to the paradigm of control, the ODM process uses current information about the state of the system, along with a multi-disciplinary approach, to provide thoroughly prepared guidance to the system operators. This approach is already being used to respond to the on-going variations that are now acknowledged as part of managing a complex system. It appears that the social properties of the ODM process add features that help to cope with complexity in the socio-technical systems that now comprise nuclear power utilities.

Limitations of Research and Ideas for Future Research

This research was limited by the need to rely on interviewee descriptions of the ODM process, rather than relying on the actual observation of the ODM process in action. This research is also limited in that it provides a description of the social process around ODM, and discusses the value of the elements identified, but it does not discuss in any detail why the various elements exist.

This research has identified that there is value in taking a close look at activities that are perceived to be closer to routine daily work for key utility staff. But the focus on ODM has also established a category of events that are quasi-abnormal, and as such could still be considered non-routine.

The ODM process is one of many problem-solving processes that could be activated by utility staff to address emerging issues. The engineering evaluation process was mentioned in this thesis, but was not described in any detail, nor was any elaboration made of the social processes that surround that process. It would be worthwhile to study the interaction of processes such as engineering evaluation, troubleshooting, and investigations, to build a greater depth of understanding of how the processes interact and function in reality, and to better understand how rationality is established within the plethora of data being studied.

It is also noted that the ODM procedure entry conditions restrict use of the process to issues with plant equipment. Interviewees confirmed that the process has not been used to address non-technical issues. A different process, study of which was outside the scope of this research, is used to addresses organisation changes. However it raises a possible question for future research regarding the socio-technical nature of a large safety critical endeavour, and how the issues are compartmentalised between 'technical' and 'organisational'.

This research has looked at the implementation of ODM at one Canadian utility. There was no attempt made to characterise the national, social or business culture in this utility and how that may influence the decision-making processes within the organisation. It would be worthwhile to repeat this work in other countries, and in a broader range of organisations, to help build a deeper understanding of how social decision making processes contribute to the construction of safety.

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APPENDIX A: INTERVIEW PROTOCOL

Interviewees were contacted individually prior to the interview date and were given a short description of the research and the description of the consent process. Each interviewee was asked to bring to mind two or three recent ODM events in which they were involved, and which they believe were challenging. As part of the interview structure each interviewee was asked to refer to a specific event to help provide a framework for discussing the ODM process.

The semi-structured interview was organised in four parts

1.0 Introduction.

1. Brief summary of the research to the informant.
2. Explanation of the informed consent process and signing the consent form.
3. Ask the interviewee for a brief summary of his/her education, years of experience within nuclear power, and career path in the nuclear industry.

2.0 Event identification.

1. Ask the interviewee to summarise a recent ODM event of interest.
2. The interview focussed the informant on the event in more detail. An exact timeline was not critical, but a general order of the steps through the event from the decision to initiate the ODM process, to the point were further action was not deemed necessary. The informant was prompted to identify who was involved, key players and key discussions (Crandall et al., 2006).

3.0 Event probes.

1. The researcher stepped through the event again and asked the informant to elaborate on key parts of this ODM event. The questions "[were] aimed at eliciting the cues and information available in the situation, the meaning they held for the participant, and the specific cognitive processes they evoked" (Crandall et al., 2006, p. 79). The questions used depended on the story being told by the interviewee, but example questions included:

    i. What were your specific goals and objectives at the time?
    ii. Is it a type of event you were trained to deal with?
    iii. Were you reminded of any previous experience?
    iv. What information did you use in making this decision?
    v. How was an option chosen or others rejected?
    vi. Did you imagine the possible consequences of this action? (Crandall et al., 2006, p. 79)

2. The researcher asked additional questions about the social interactions that occurred. For example;
    a. What was the mood or atmosphere of the ODM meeting?
    b. Was everyone at the ODM meeting involved in the discussion?
    c. Are you aware of a situation where a specialist in one area raised an issue in another area?

d. Were any issues raised that initially sounded completely 'off-the-wall'?
e. Did any individual identify a brand new issue during a group discussion that had not been previously foreseen?
f. Did anyone raise an issue based on 'gut-feel'? If so how did the team/organisation respond?

4.0 Interview closing.

1. Based on our discussion, is there anything else that springs to mind you would like to tell me?
2. Thank the informant for their time and involvement in the project. Remind them of my contact information and ask their permission to contact them should I need to ask a follow up question.